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SUMMARIZING REPORT OF THE ACTIVITIES OF THE FSU RADIO OBSERVATORY, 1960-1969

INTRODUCTION

The Florida State University Radio Observatory was established in September, 1960 with the aid of a $5000 grant from the University Research Council. Three broadside arrays and a square corner reflector were constructed on a site of land adjoining the University campus and radio observations of the planet Jupiter at frequencies of 18.3, 18.7, 19.5 and 24.0 Mc/s were commenced during the 1961 apparition. The antennas operating at 18.3 and at 24.0 Mc/s consisted of arrays of crossed dipoles which permitted a qualitative assessment of polarization sense to be made. At this time, the Jupiter radiation was known to be almost exclusively right-handed (R.H.) polarized at 22 Mc/s but nothing was known of the polarization at other frequencies. Probably the most significant information to appear from these first observations was that the proportion of R.H. polarization appeared to be appreciably less at 18.3 than at either 22 or 24 Mc/s. This was the first indication to be found of any pecularities in the polarization of the Jupiter radiation.

In 1962, NASA began to support the program and this support continued until the untimely departure of the Principal Investigator in November, 1968 by order of the U. S. Immigration Authorities.

From 1962 onwards the program grew steadily and in the summer of 1965 the Radio Observatory moved to a larger site of some eleven acres situated several miles from the city of Tallahassee. The broadside arrays had already been replaced in 1962 by steerable alt-azimuthally mounted crossed five element Yagis operating as polarimeters at frequencies of 16, 18, 22, and 26 Mc/s; these were transferred to the new site. In addition, an 18 Mc/s phase-switched interferometer was installed. This, at first, consisted of two broadside arrays, each of eight half-wave dipoles on a 16 wavelength baseline. Each array was later enlarged to 20 half-wave dipoles and phased to allow north-south steering of the beam. Other arrays operating at 12.5, 14.0, and 30 Mc/s were constructed and used during the period 1965-1968 as well as 18 Mc/s null antennas.

During the period 1962-1969 a number of graduate students worked on the project and five M.S. and two Ph.D. degrees were completed. Two senior research associates also worked on the project for a part of the period.

As the project developed the main interest concentrated upon the polarization and short time-resolution burst structure of the radiation. Other areas included the detection of a weak background continuum radiation with the phase-switched interferometer, a determination of the solar wind parameters from separated site observations, a theoretical study of the upper atmosphere of Jupiter, a search for

decameter emission from Saturn using the Arecibo reflector at 16 and 18 Mc/s., and routine daily observations for catalogues of activity and for the development of a prediction computer program for Jupiter activity, based upon the Io effect. Each of these areas is described below. In some cases the summary covers work done over a period of several years and reference should be made to the various publications listed for a more detailed chronological development of each area.

1. POLARIZATION

At the beginning of the project, polarization observations were made at frequencies of 16, 18, 22, and 26 Mc/s using the crossed Yagi antennas. Initially, only L.H. and R.H. components were observed but later, phase and correlation measurements were added at 18 Mc/s so that the degree of polarization could be determined.

The two component measurements indicated that at all four frequencies R.H. polarization predominated although the proportion of L.H. polarization was considerable greater at the two lower frequencies and apparently associated with the Jovian B and C sources.

At 18 Mc/s, the later observations indicated that almost half of the bursts studied were circularly polarized and possibly superimposed upon a randomly polarized background. The remainder of the bursts were distributed around an axial ratio of about 0.35 roughly in the manner predicted by the

Doppler-shifted cyclotron theory of Ellis and McCulloch. The degree of polarization was generally rather high, being greater than 0.7 for some 80% of the bursts analyzed.

The effect of assuming 100% polarization for all bursts (as is often the procedure when only left and right components are measured) is to obscure the amount of circular polarization present, as this may be superimposed upon a randomly polarized background and cannot be distinguished from pure elliptical polarization without a determination of the polarization fraction. Allowing for this, the results are consistent with some of the predictions of the Ellis and McCulloch Theory.

The overall accuracy of these observations and also the effects of terrestrial Faraday rotation was studied in some detail and discussed in the published accounts of the work.

Events occur occasionally which may be linearly polarized but these could also be due to almost simultaneous oppositely polarized bursts, (See note under Section 2).

2. FAST PULSES AND BURST STRUCTURE

Left- and right-hand components of polarization were measured at 16, 18, 22, and 26 Mc/s with various time resolutions from 0.1 sec down to 0.5 millisec. Very fast pulses having durations of the order of a few milliseconds and bandwidths of the order of a megacycle or so are sometimes present in the radiation. These pulses (which we have

called I-pulses) appear to be associated with the B and C sources on Jupiter but independently of the L.H. polarization association mentioned in the previous section.

At the shortest time resolution it was found that some apparently random/linear* polarized bursts appear as successions of very fast oppositely polarized short pulses.

3. INTERFEROMETER AND CONTINUUM

A weak, fairly steady amplitude, continuum background to the characteristic bursty radiation was detected on a number of occasions using the 18 Mc/s phase-switched interferometer.

4. 38 Mc/s OBSERVATIONS

A series of interferometer observations at 38 Mc/s in 1962 established that the Jupiter radiation could, very occasionally be detected at this high a frequency. Previously it had been taken for granted by most workers (influenced by a few negative observations obtained at Cambridge, England, with an antenna of high sensitivity) that the upper frequency limit to the radiation occurred somewhere below 38 Mc/s.

5. SPACED-SITE OBSERVATIONS

(a) Short baseline.

During 1967 and 1968 a number of observations were made from three sites (one of which was the main observatory at Tallahassee) forming an approximate right-angle triangle

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*The two component polarimeter systems used for this work could not distinguish between random and linear polarization as they did not measure sufficient parameters. The more elaborate 18 Mc/s system could make this distinction but did not have the time resolution necessary to see if fast pulses were present.

having baselines of a few miles. Identical 18 Mc/s equipment at each site allowed interplanetary scintillations of the Jovian emission to be studied for solar elongations greater than 90°. The observations indicated that the electron density irregularities appear anisotropic and may be elongated along the solar magnetic field lines frozen into the radially expanding solar wind. The intensity distributions suggest that the observed fluctuations are imposed on the decametric emission by irregular diffraction in the interplanetary medium although the magnitudes are determined by both the probability distribution and intrinsic source variation on the same time scale as the interplanetary scintillations. Some measurements of the solar wind velocity indicated values of the order of a few hundreds of km/sec.

This work was in progress at the closure of the project and much remains to be done. The experimental equipment is completely set up and the data processing procedures are established but no one is now available to continue the work. The above results were obtained essentially from limited data samples as part of a Ph.D. project by Thompson.

(b) Long baseline.

Simultaneous observations at 18 Mc/s from five stations along a north-south line from Trondheim, Norway, to Grahamstown, South Africa, were conducted in an attempt to assess the effect of the Earth's ionosphere upon the radiation. The limited results obtained indicated that the ionosphere may be having a considerable effect as, on several occasions,

it appeared that the amounts of activity, recorded simultaneously under good conditions at the five stations, were very different in both intensity and duration. This is believed to be a real result in spite of the numerous difficulties mentioned below.

Of all of the experiments attempted, this one proved to be the most disappointing and frustrating for purely non-scientific reasons. The results, while interesting, were inconclusive because of insufficient data. It is worth noting that while this type of experiment is potentially extremely interesting and rewarding (being an almost untouched field) the purely operational problems involved make the cost considerable and far higher than the amount involved in the project described here. In the present opinion of the writer it is not worth attempting this type of experiment unless a fully trained operator-supervisor is resident at each station during the observing period, the equipment is simple but of high quality and reliability with replacement units quickly available, and adequate funding available for communications and travel.

6. UPPER ATMOSPHERE OF JUPITER

The Kuiper model atmosphere and, later, the Trafton model, having He:H ratio unity, were used as the bases of theoretical studies of the upper atmosphere of Jupiter somewhat along the lines of the work of Gross and Rasool but including the effects of thermal opacity of H_2 neglected by these workers. Absorption of solar ultraviolet is shown to

result in the formation of an ionosphere a few hundred kilometers above the cloud top. Models based upon hydrogen absorption and upon hydrogen plus helium absorption are considered. In both cases the maximum electron density is of the order of 5×10^5 cm^{-3}. A detailed account is being submitted for publication.

7. SATURN OBSERVATIONS

An attempt was made to detect decameter-wave radiation from the planet Saturn using the following equipment:

(a) The Arecibo 1000 ft. reflector using two two-element Yagis at 16 and 18 Mc/s crossed on a common boom.

(b) The FSURO 18 Mc/s phase-switched interferometer with each array enlarged to 20 half-wave dipoles.

(c) A 26 Mc/s swept frequency antenna array built at Clark Lake Radio Observatory by Resch, a member of the FSU Group.

As Saturn moved to a northerly declination, a search for decameter radiation was an obvious investigation to make. If such radiation exists, however, it must be weaker than the corresponding Jupiter emission by more than the inverse-square law factor; otherwise it would already have been detected by existing Jupiter equipment.

Several periods of activity were recorded at both Arecibo and Tallahassee which were regarded as interesting and possibly significant. A histogram of these observations shows two peaks almost exactly 180° apart if based upon the

longer of the Saturn optical rotation periods. Each peak corresponds to four periods of activity. Further observations need to be made but this has not been possible because of the closure of the project. No activity was recorded at 26 Mc/s.

Jupiter and Saturn are known to have many physical similarities and an interesting aspect of this experiment is that it could help to clarify the Jupiter radiation mechanism. No matter whether the final result is found to be positive or negative, a comparison of the known physical properties of the planets should allow some to be retained or eliminated as possible contributors to the Jupiter radiation process.

8. ROUTINE DAILY OBSERVATIONS, CATALOGUES AND PREDICTIONS

In the course of the more specialized observations routine daily observations have been made throughout each apparition from 1961 - 1968. Computer programs were developed for processing and tabulating the data as well as for a graphical presentation, in the form of histograms, of occurence probability and the Io effect. Two catalogues of activity covering the years 1961 - 1964 and 1965 - 1967 were published.

Another computer program was developed in 1965 for predicting the most probable times for Jupiter activity. This program utilized the Io effect and presented tabulated predictions as well as a Universal Time diagram of the probable activity periods. During the 1965 apparition the predictions were found to be some 85% successful and the

program has since been requested by several other groups of Jupiter observers.

Most of the observational data was made available to the NASA Space Science Data Center for microfilming and cataloguing in the Center's files.

PUBLICATIONS

Papers

Recent Radio Observations of Jupiter at Decameter Wavelengths, C. H. Barrow, Astrophys. J. 135, 847 (1962).

38 Mc/s Radiation from Jupiter, C. H. Barrow, Nature 197, 580 (1963).

A Brief Survey of the Decameter-Wave Radiation from Jupiter, C. H. Barrow, J. Brit. Ast. Assn. 73, 42 (1963).

A Note on the Polarization of 16 Mc/s Radiation from Jupiter, C. H. Barrow, Nature 201, 171 (1964).

An Experiment to Study the Relationship between Radio Noise from Jupiter and Solar Activity, C. H. Barrow and F. W. Hyde, J. Brit. Ast. Assn. 73, 327 (1963).

Mysterious Radio Emissions from the Planet Jupiter, F. W. Hyde, New Scientist 19, 432 (1963).

Radio Astronomy, F. W. Hyde, J. Soc. Engr's. 14, 195-221 (1963).

Polarization Observations of Jupiter at Decameter-Wavelengths, C. H. Barrow, Icarus 3, 66 (1964).

Preliminary Results of Spaced-Site Observations of Jupiter in 1963, C. H. Barrow, G. M. Resch, F. W. Hyde, G. M. Gruber and M. C. Bosch, Nature 204, 637 (1964).

1964 Astronomical Year Book, (Eyre and Spottiswoode, London, 1964) Chapter entitled "The Radio Sun," F. W. Hyde.

Recommendations for Standardization of Reporting Procedures, J. K. Alexander, C. H. Barrow, F. Six, (Circular summarizing discussion session of the Jupiter Observers Conference, NASA/University of Maryland Conference, Greenbelt, April 26-27, 1965).

A Catalogue of Radio Observations of Jupiter, 1961-1964, D. P. Morrow, C. H. Barrow and G. M. Resch, Florida State University Radio Observatory Report, November 1966.

PUBLICATIONS

Papers continued

Report of the Florida State University Radio Observatory, (1965), C. H. Barrow, Astronomical Journal 70, 767 (1965).

An Investigation of a Possible Correlation Between Jupiter Activity and Solar Activity, G. M. Resch, M.S. Thesis, Florida State University, December, 1965.

Radiostøyen fra Jupiter, H. Torgersen, Fra Fysikkens Verden Nr. 4, 77 (1965) (In Norwegian).

Millisecond Radio Pulses from Jupiter, E. E. Baart, C. H. Barrow and R. T. Lee, Nature 211, 808 (1966).

A Study of the Millisecond Pulses Contained in the Decametric Radiation from Jupiter, R. T. Lee, M.S. Thesis, Florida State University, July 1966.

The B and C Sources on Jupiter, C. H. Barrow and E. E. Baart, Nature 213, 165 (1967).

Report of the Florida State University Radio Observatory, (1966), C. H. Barrow, Astronomical Journal 72, 257 (1967).

Measurement of Four Parameters of Polarization, D. P. Morrow, M.S. Thesis, Florida State University, April (1967).

Evidence of Continuum Emission from Jupiter at 18 Mc/s, C. H. Barrow and J. Williams, Nature 216, 462 (1967).

A Scanner for Short Sections of Magnetic Recording Tape, H. Torgersen, Review of Scientific Instruments 38, 1788 (1967).

A Catalog of Radio Observations of Jupiter, 1965-67, J. Williams, J. D. Merritt, D. P. Morrow and C. H. Barrow, Florida State University Radio Observatory Report, September, 1967.

The Polarization of the Jupiter Radiation at 18 Mc/s, C. H. Barrow and D. P. Morrow, Astrophysical Journal 152, 593 (1968).

PUBLICATIONS

Papers Continued

Report of the Florida State University Radio Observatory, (1967), C. H. Barrow, Astronomical Journal 73, S129 (1968).

The Upper Atmosphere of Jupiter, L. Capone, M.S. Thesis, Florida State University, August, 1968.

Report of the Florida State University Radio Observatory,(1968), C. H. Barrow, Bulletin of the American Astronomical Society 1, 12 (1969).

A Radio Study of the Planet Jupiter, C. H. Barrow, Ph.D. Thesis, London University, September, 1968.

Improved Measurement of Phase and Coincidence Between Two Signals with an Oscilloscope (In Norwegian), H. Torgersen, Electroteknisk Tidsskrift, 1968.

The Upper Atmosphere of Jupiter, L. A. Capone and C. H. Barrow, (Paper submitted for publication).

An Analysis of the Intensity Fluctuations Produced by the Interaction of the Decametric Radio Emission from Jupiter with the Interplanetary Medium, D. L. Thompson, Ph.D. Thesis, Florida State University, December 1969.

Structural Differences in the Jupiter Millisecond Pulses, H. Torgersen, Physica Norvegica 3, 195 (1969).

PUBLICATIONS

Abstracts

Decameter-Wave Observation of Jupiter in 1961, C. H. Barrow, Astron. J. 67, (1962).

Polarization Observations of Jupiter at Decameter Wavelengths, C. H. Barrow, Proceedings of the 11th Astrophysical Symposium, Liege, 1962. La Physique des Planetes (Cointe Sclessin, Belgium, 1963) p. 563.

Polarization Observations of Jupiter at Decameter-Wave Frequencies, C. H. Barrow, Trans. A. G. U. 44, 887 (1963).

Decameter-Wave Observations of Jupiter in 1963, C. H. Barrow, Bull. Am. Phys. Soc., Series II 9, 352 (1964).

A Spaced-Site Experiment to Search for Possible Correlations Between Decameter-Wave Radiation from Jupiter and Solar Activity, C. H. Barrow, Bull. Am. Phys. Soc., Series II 10, 249 (1965).

Measurement of the Stokes Parameters of Jupiter Radiation at 18 Mc/s, C. H. Barrow and D. P. Morrow, Bulletin of the American Physical Society, Series II 11, 851 (1966).

Millisecond Pulses in Jupiter Radiation, E. E. Baart, C. H. Barrow, R. T. Lee, Astron. J. 71, 377 (1966).

Polarization of the Jupiter Radiation, C. H. Barrow, E. E. Baart, D. P. Morrow, Proceeding of the URSI-USNC Neeting, Washington, D. C., April 1966.

A Catalogue of Jupiter Activity, 1961-1964, D. P. Morrow, C. H. Barrow, Bulletin of the American Physical Society, Series II 11, 512 (1966).

Solar-Jupiter Relationships, G. M. Resch, C. H. Barrow, Bulletin of the American Physical Society, Series II 11, 512 (1966).

Bursts and Pulses in the Jupiter Decameter Emission, H. Torgersen, Astron. J. 72, 832 (1967).

Abstracts continued

Possible Continuum Emission from Jupiter at 18 Mc/s, C. H. Barrow and J. Williams, Astron. J. 72, 785 (1967).

Polarization of the Jupiter Radiation at 18 Mc/s, C. H. Barrow and D. P. Morrow, URSI Spring Meeting, Ottawa, Canada, May, 1967.

Instrumental Effects in Polarization Measurements of the Decameter-Wave Radiation from Jupiter, C. H. Barrow and D. P. Morrow, SEAPS Meeting, Clemson, South Carolina, (November 4, 1967). Bulletin of the American Physical Society, Series II 13, 251 (1968).

The Upper Atmosphere of Jupiter, L. A. Capone and C. H. Barrow, Bulletin of the American Physical Society, Series II 13, 1715 (1968).

Interplanetary Scintillation of Jupiter's Radio Emission, D. L. Thompson, Bulletin of the American Physical Society, Series II 13, 1714 (1968).

The Upper Atmosphere of Jupiter, L. A. Capone and C. H. Barrow, Inaugural Meeting, Planetary Division, American Astronomical Society, Austin, Texas, December 1968.